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Blowing snow in Antarctica: 3 years of continuous observations in Adélie Land

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ABSTRACT: The Surface Mass Balance (SMB) of the Antarctic ice sheet is probably the only important negative contribution to the sea-level rise. Net erosion of snow by the wind may contribute significantly to the SMB of the Antarctic costal zone. However, there are very few field observations to confirm this hypothesis and to evaluate numerical models developed for this purpose. Adélie Land, located in East Antarctica, is one of the windiest places in the world in term of mean wind speed at the coast. Furthermore, the frequency of the blowing snow events, determined by visual observations, is very high. That is why a field campaign was launched in January 2009 to acquire new model-evaluation-oriented observations in the framework of the European project ICE2SEA and with the logistical support of the French polar Institute (IPEV). Three automatic weather and snow stations, including acoustic sensors for the aeolian transport of snow named FlowCapt, have been deployed in Adélie Land. The stations locations are distinct ranging from 1 to 100 km inland. One of them is a 7 m-mast with 6 levels of anemometers and thermo-hygrometers. Thus, the campaign can assess, inter alias, transport events periods, transport frequencies, snow quantities transported, threshold friction velocities and the ratio between small and large fluxes events. Those results can be use in the evaluations of the regional climate models.

KEYWORDS: Aeolian transport, Blowing snow, drifting snow, Antarctica, FlowCapt.

1 INTRODUCTION

The first polar expeditions in Antarctica highlight the importance of the aeolian transport of snow (Madigan, 1929; Prud'homme and Valtat, 1957). During those expeditions, coupled to the visual observations, basic traps were constructed to evaluate the snow quantity transported (Garcia, 1960; Madigan, 1929).

The terms blowing snow and drifting snow are mainly used to characterize the transport of snow by the wind. They are distinguished by the maximum height reached by the particles and their influence on the visibility (Leonard et al., 2011). The American Meteorological Society defines drifting snow as an event with a maximum particles height below two meters and no influence on the visibility. Blowing snow represents the event when particles maximum heights are above two meters with a reduction of visibility. Here we consider both types of transport and we will speak about the aeolian transport of snow regardless the maximum height of particles or if it is occurring with or without precipitation.

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Different technics have been developed since the first expeditions and several campaigns that include aeolian transport of snow have been conducted in Antarctica. The most used sensors in those campaigns are the mechanical traps (Budd et al., 1966; Garcia, 1960; Kobayashi, 1978; Lorius, 1962; Madigan, 1929; Takahasi, 1985) but optical sensors have been used (Leonard et al., 2011; Mann et al., 2000; Nishimura and Nemoto, 2005; Wendler, 1989, 1987) as well as piezo-electric sensors (Bintanja et al., 2001; Leonard et al., 2011) and acoustic sensors (Scarchilli et al., 2010). All the observations have confirmed the importance of the snow transported by the wind in term of frequency and quantity in different Antarctic regions.

Regional Climate Models (RCMs) with a parameterization of the aeolian transport of snow can evaluate its effect on the Antarctic surface mass balance (Gallée et al., 2005; Lenaerts et al., 2012b). However, they need an accurate evaluation in Antarctica.

Such evaluations are difficult because aeolian transport observations are few and far between (Lenaerts et al., 2012a). Furthermore, no standard of the aeolian process measurements exist (Barchyn et al., 2011) making intercomparisons between campaigns difficult.

In order to accurately evaluate a RCM, several points have to be taken into account. Firstly, data have to be acquired in different locations with comparable values. Secondly, data have to be integrative over the height with a temporal resolution of one hour or less as RCMs have a coarse resolution near the ground with a fine temporal resolution. Thirdly, data have to last one year or more to evaluate RCMs in different conditions and over long periods.

None of the observations already made in Antarctica matches all these constraints. We will present here a new, model-oriented campaign of aeolian transport of snow, which has been launched in 2009 in order to accurately evaluate RCMs.

2 ADELIE LAND, AN IDEAL PLACE FOR THE AEOLIAN TRANSPORT OF SNOW

Adélie Land is located in East Antarctica (Figure 1). Many meteorological observations have been undertaken there since the first ones conducted during the Australasian Antarctic Expedition lead by Mawson in 1911.

Figure 1. Localisation of the aeolian transport of snow observations in Adélie Land (red square), East Antarctica (source: Google Earth)

Adélie Land is characterized by strong and frequent katabatic winds which are the strongest in terms of mean wind speed at sea level in the world (Wendler et al., 1997). They are very often associated with aeolian transport of snow, for example 45 % of the time during the year 1950 and 1951 at Port Martin Station (Prud'homme and Valtat, 1957) and even 97 % of the time in September 1958 at the Charcot Station (Garcia, 1961).

The snow quantity transported is very large. Lorius (1962) estimated a lower value of the snow blown from the continent into the sea at 0.29 10^6 kg per meter of coast around Dumont D'Urville Station. The estimated annual transport rate is 0.4 10^6 kg.m^{-1} at the Charcot station for the year 1958 with mechanic traps (Garcia, 1960) and around 6.3 10^6 kg.m^{-1} at the D47 point with optical sensors for the year 1985 (Wendler, 1987). In addition to these observations, a 1-D modelling determined that the wind erosion is the largest contributor to ablation on the coastal blue-ice areas near Dumont D'Urville station (Genthon et al., 2007).

Furthermore, a 40-years accumulation dataset is available in Adélie Land and is still operating (Agosta et al., 2011). Thus, RCMs can be evaluated on the surface mass balance and the aeolian transport of snow. All these characteristics made Adélie Land an ideal place to conduct observations of aeolian transport of snow.

3 INSTRUMENTS

In order to be installed in remote locations, the sensors have to stand the harsh polar environment for one year in autonomy. Indeed, the sensor location can only be visited during the austral summer. The FlowCapt is the sensor of aeolian transport of snow with the highest ratio advantages/disadvantages for the two types of constraints coming from the model and from the environment.

The FlowCapt is an acoustic sensor commercialized by IAV technology. It records the acoustic pressure generated by the particle impacts on a hollow tube and determines the particle flux from the acoustic pressure with a standard calibration (Chritin et al., 1999). The flux is averaged over 10 minutes or more. It can stand the harsh polar environment and has few power requirements (Savelyev et al., 2006; Scarchilli et al., 2010).

The tube can be 30 cm or 1 m long and is designed to be placed vertically. Thus the fluxes are vertically integrated. When the lower end of the sensor lies close to the ground or when it is partially buried, the FlowCapt is able to detect the beginning of the transport. As the snowpack level changes during the year (Favier et al., 2011) this sensor presents an advantage over single point measurements sensors.

Two generation of FlowCapts exist. They both have the same calibration technics and use the same software. The second generation, available since 2009, has an improved hardware and each FlowCapt is individually calibrated.

The first generation FlowCapts have already been evaluated for research purposes (Cierco et al., 2007). A careful evaluation of the first and second generation FlowCapts has been lead in the French Alps during the winter 2011-2012. The results confirm the first evaluation: the first generation FlowCapt cannot determine the fluxes. However it is a good detector of the aeolian transport events. The second generation FlowCapt is a good detector but it can also estimates a lower value of the snow quantity transported in one location.

4 AUTOMATIC WEATHER AND SNOW STATIONS

FlowCapts have been added to the classical automatic weather station installed in Adélie Land (Favier et al., 2011), to form an Automatic Weather and Snow Station (AWSS). Several of those stations have been installed in Adélie Land since 2009 (Table 1).

Table 1. Characteristics of the Automatic Weather and Snow Stations set-up in Adélie Land. 1G and 2G mean respectively first and second generation. Annual mean wind speeds come from (Parish and Wendler, 1991)

	D3	D17	D47
Location	66.694 S, 139.89 E 110 m asl	67.724 S, 139.70 E 465 m asl	67.393 S, 138.709 E 1565 m asl
Date of installation	February 2009	February 2010	January 2010
Surface mass balance	Zero	Positive	Positive
Aeolian transport measurements	1G FlowCapt 0-1,1-2 and 2-3 m	2G FlowCapt 0-1 and (2010) 4.5-5.5 m	2G FlowCapt 0-1 and 1-2 m
Annual Mean wind speed	8.3 $m.s^{-1}$ (at D10)	10.5 $m.s^{-1}$	11.1 $m.s^{-1}$

4.1 D3

The D3 AWSS was the first station installed in 2009. It is located 1 km from the coast at a null surface mass balance location (Agosta et al., 2011). As sensors for this station have been purchased in 2008, it is composed of three one-meter first generation FlowCapts from 0 to 1 m, 1 to 2 m and 2 to 3 m (Figure 2). An aerovane, a thermo-hygrometer and a snow height sonic sensor are installed five meters away. Due to a datalogger malfunction, no data is available for July, August and September 2009.

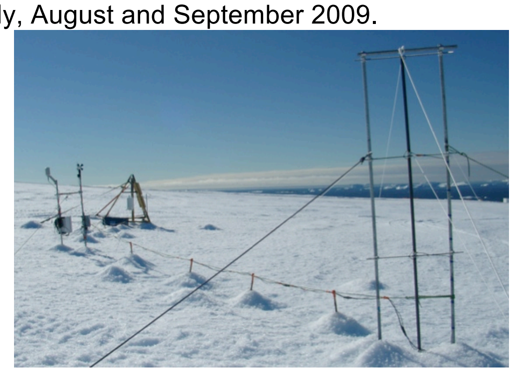

Figure 2. The D3 Automatic Weather and Snow Station. The three one-meter first generation FlowCapts in January 2010 are in the foreground

4.2 D17

The D17 AWSS is set-up 10 km from the coast and represents the best compromise between accessibility and inland location with strong katabatic winds. The station is composed of a 7 m-mast with 6 levels of cup anemometers and thermo-hygrometers (Figure 3). Two one-meter second generation FlowCapts are installed from 0 to 1 m and 4.5 to 5.5 m. The station was installed in February 2010. The upper FlowCapt was removed due to malfunction in January 2011. The threshold friction velocity can be calculated.

Figure 3. The D17 7 m-mast Automatic Weather and Snow Station in February 2010 with the two one-meter second generation FlowCapts

4.3 D47

The D47 AWSS is located approximately 100 km from the coast where the annual mean wind speed is the strongest on the transect Dumont D'Urville-Dome Concordia (Parish and Wendler, 1991). The station is composed of two one-meter second generation FlowCapts installed from 0 to 1 m and 1 to 2 m with an aerovane, a thermo-hygrometer and a snow height sonic sensor (Figure 4).

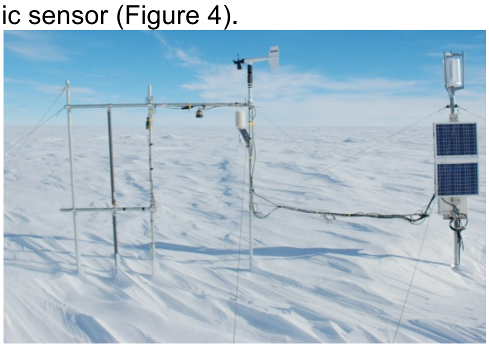

Figure 4. The D47 Automatic Weather and Snow Station in January 2011 with the two one-meter second generation FlowCapts

5 CONCLUSION

A new, model-oriented campaign on the aeolian transport of snow has been launched in 2009 and is still operating. Evaluation of regional climate models on the transport events can be done at three points with classical meteorological data. The transport rate can be obtained at two points from 0 to 1 m at D17 and 0 to 2 m at D47. A D17, the observed threshold friction velocity determined can be compared to the simulated ones.

A first evaluation of the MAR model has already been undertaken over January 2010 with the automatic weather and snow station D3 (Gallée et al., 2012). Further evaluations can be done with the other stations, but also on a longer period with the MAR model and other regional climate models with a parameterization of the aeolian transport of snow.

Observations of aeolian transport of snow in Antarctica are scarce. To our knowledge, these three years observation period is the longest period in Antarctica with automatic sensors. Thus, this campaign is valuable for the knowledge of Antarctica meteorological conditions as well. It can assess, inter alias, transport events periods, transport frequencies, snow quantities transported, threshold friction velocities and evaluate the ratio between small and large fluxes events. Such information is a complement to the remote sensing technics information (Palm et al., 2011).

Additional sensors and measurements will be conducted in the future to acquire better and more precise information on the aeolian transport of snow.

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